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Improvised Munitions

From Ammonium Nitrate

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Abstract

WARNING

The material contained herein is published in the interest of historical and technical enlightenment only. The manufacture, transportation and detonation of improvised munitions may be in direct violation of state and local laws as well as Federal statutes and regulations governing such devices. Additionally, experimentation with unstable explosive devices is highly dangerous and may result in serious injury or even death.

During the 1960's, a program was conducted to determine a safe and simple method for producing an ammonium nitrate munition using indigenous materials. Sensitivity tests were performed on mixtures of fuel oil and fertilizer grade ammonium nitrate (FGAN) to determine differences in FGAN manufactured by Stengel, prilling and crystallization processes. Prilled FGAN was selected for further testing since it functioned satisfactorily and is the most common form available. Since FGAN, either as received or finely pulverized, was insensitive to five No. 6 electric blasting caps, various indigenous materials were added to FGAN to increase sensitivity. Shock sensitivity and brisance of these FGAN/sensitizer mixtures were determined as functions of communiton technique, sensitizer concentration, confinement, packing density and initiator type and size. The most sensitive explosives, as evidenced by a punctured witness plate, consisted of finely ground FGAN thoroughly mixed with 5 weight per cent fuel oil, motor oil, motor oil/gasoline mixtures, ethylene glycol or paint thinner. These mixtures were reliably detonated with a single No. 8 electric blasting cap when confined in 1- or 2-inch diameter "tin" cans and beer bottles, provided that the packing density was less than 0.78 gm/cc. The FGAN sensitizer in this munition is about as brisant as riced trinitrotoluene (TNT). A set of instructions is included herein; the instructions consist of illustrated, simple, step by step procedures for fabricating fertilizer explosives.

I. Introduction

To assist in the compilation of an Improvised Munitions Handbook, which describes methods for fabricating weapons and for producing explosives from readily available indigenous materials, a program was undertaken to study means of sensitizing and/or detonating fertilizer grade ammonium nitrate (FGAN) for use as an explosive.

Although FGAN may be used as an explosive when admixed with sensitizers, by itself it is insensitive to detonation using conventional blasting caps. Hence, materials which would be available in most areas of the world were to be evaluated as sensitizing additives which would permit detonation of FGAN with conventional blasting caps. Based on a thorough literature search to be undertaken at the outset of the program, as well as prior experience in explosives technology, methods were to be developed for sensitizing small quantities of FGAN which could then be used as booster charges for much larger quantities of unsensitized material. This study was also to include a search for: (1) additives which would sensitize FGAN to detonation above some pre-determined threshold temperature; and (2) additives which would immediately cause detonation when added to the main charge by some mechanical means.

Mixtures of FGAN and the most promising additives were to be evaluated for brisance, shock sensitivity, temperature sensitivity and related explosive parameters.

The sensitizers or additives were restricted to "indigenous" materials, such as straw, wood, fuel oil, gasoline, common household chemicals, medicinals and related materials which should be available throughout the world including the "underdeveloped" or "backward" countries. In no case were materials considered which would be difficult or impossible for a guerrilla force to obtain.

II. Discussion

Since the end item for this program is a set of instructions intended for use by persons with little or no prior experience in explosives technology, the selected procedures ensure a high degree of safety and simplicity. The set of instructions, intended for inclusion in the Improvised Munitions Handbook, consists of simple, step by step procedures supplemented with illustrations.

2.1 Explosives: Sensitivity and Brisance

Explosives are thermodynamically unstable materials which, when subjected to an external stimulus (usually a severe mechanical shock) undergo an extremely rapid, exothermic decomposition to produce gaseous products at very high temperature and pressure capable of doing mechanical work by expansion.

The magnitude or severity of the external stimulus required to initiate the decomposition is customarily used as a measure of the sensitivity of the explosive.

The rate of decomposition, that is, the rate of energy release, which is the most characteristic feature of an explosion, is a measure of the ability of an explosive to effect local destructive action by means of the sudden shock of the detonation products through the surrounding medium. This ability to destroy or shatter by sudden shock is called brisance and is only observed in the immediate proximity of the explosion site where the energy density and pressure of the explosion products are quite high.

The sensitivity and the detonation velocity of explosives are variable characteristics which are dependent not only on differences in chemical composition but also on variations in the physical state of a given explosive.

2.2 Ammonium Nitrate

2.2.1 Commercial Ammonium Nitrate

Ammonium nitrate is made commercially in this country by the reaction between ammonia and aqueous nitric acid. Three commercially important techniques are employed in

the isolation of ammonium nitrate from its aqueous solution; viz., the Stengel, prilling and crystallization processes. The resultant products are chemically identical but differ in particle geometry.

The Stengel process consists of heating a concentrated aqueous solution in an air stream above the melting point of the salt to obtain dry, molten ammonium nitrate. The molten product is collected and condensed into sheets on a water-cooled conveyor belt. The sheets pass through a breaker to produce flakes which, if desired, may be further reduced in size.

In the prilling process, a concentrated solution of ammonium nitrate falls in the form of small droplets in a prilling tower against an upward stream of air to yield slightly moist, small, rounded pellets or prills. The prills are screened, dried and air-cooled.

The crystallization process consists of concentrating an aqueous solution in a vacuum crystallizer to produce a slurry. The slurry is then centrifuged to separate and dry the ammonium nitrate crystals.

American-manufactured fertilizer grade ammonium nitrate (FGAN), principally made by the prilling process, is ammonium nitrate which has been first coated with from 0.5 to 1 per cent of a water repellent substance, generally a wax and clay mixture, to decrease hygroscopicity, and then mixed with from 3 to 5 per cent of an anticaking agent such as kaolin, kieselguhr or plaster of paris. The material is then sized and packaged in moisture-proof bags.

2.2.2 Ammonium Nitrate Explosives

Ammonium nitrate has steadily increased in importance as an industrial explosive ingredient since the Swedish chemists Norrbin and Ohleson patented their explosive mixtures of ammonium nitrate with various combustibles including charcoal, sawdust and naphthalene. Its extensive use has been due primarily to its low cost, ease of handling and low temperature of explosion.

The principal disadvantage of ammonium nitrate is its

tendency to cake or pack when exposed to humid environments. This has been overcome to some extent by the addition of small quantities of hydrophobic materials which coat the ammonium nitrate particles and thereby shield them from atmospheric humidity.

2.2.2.1 Variables Affecting Sensitivity and Detonation Velocity

In general, both sensitivity and detonation velocity (i.e., brisance) of ammonium nitrate explosives increase with an increase in: (1) charge diameter, (2) confinement (i.e., strength of the envelope in which the explosive is contained), (3) the presence of combustible impurities and (4) temperature. Both sensitivity and detonation velocity increase with a decrease in particle size. Sensitivity decreases and detonation velocity increases with an increase in charge density. The extent to which these variables influence the sensitivity and brisance are discussed below.

2.2.2.2 Combustible Impurities

Pure, unconfined ammonium nitrate cannot ordinarily be initiated to complete detonation with a Number 8 blasting cap. On the other hand, ammonium nitrate mixtures containing from 2 to 20 per cent of various organic nitrate esters and/or nitro compounds comprise the majority of the current industrial explosives.

Of interest to this program are references to the use of materials such as charcoal, fuel oil, pulverized seaweed, sawdust, wood flour, coal tar and paraffin as sensitizers for ammonium nitrate. The ammonium nitrate-fuel oil (AN/FO) system, introduced as an explosive following World War II, is perhaps the most popular blasting mixture presently in commercial use. This is frequently prepared in the field by simply pouring enough Number 2 diesel oil into a bag of FGAN to wet the prills, although a stoichiometric mixture (5.7 per cent fuel oil) is preferred for mining operations to minimize formation of toxic gases. There appears to have

been no attempt at a systematic study of the degree of sensitization which could be achieved by nondetonable combustibles until Cook and Talbot undertook a study of hydrocarbon sensitizers for ammonium nitrate. These investigations demonstrated that moderately fine grained (approximately 48 to 100 mesh) ammonium nitrate, coated with from 0.75 to 1.5 per cent wax, was consistently sensitive to a Number 6 blasting cap and was capable of propagation of a detonation wave indefinitely in 1.875-inch diameter charges. At fuel concentrations up to 5.6 weight per cent (i.e., stoichiometric mixture) sensitivity declined. A coarser grained ammonium nitrate (predominantly 35 to 65 mesh) containing the same hydrocarbon content was relatively insensitive to a Number 6 blasting cap.

These investigators noted further that, although the explosion temperature of explosive ammonium nitrate/hydrocarbon mixtures is in the range of 270° to 350° C, the presence of bagging paper or cellulose lowers the explosion temperature to about 150° C.

Subsequent reports of different hydrocarbon concentrations for maximum sensitivity emphasize the importance of subtle variations in particle size, packing density, intimacy of mixtures, etc., on the degree of sensitivity of the various mixtures. In particular, it was encouraging to note that one group demonstrated a constant blasting cap sensitivity for an AN/FO mixture over the range of 1 to 7 per cent fuel oil concentration.

2.2.2.3 Confinement and Charge Diameter

The influence of confinement and charge diameter on sensitivity and detonation velocity of explosives are best considered together. Most explosives possess a critical minimum diameter below which a self-sustained detonation wave will not propagate; that is to say, the materials are not sensitive to initiation. This minimum critical diameter (which is a measure of sensitivity) generally decreases with: (1) increasing confinement, (2) an increase in sensitivity and (3) a decrease in particle size of the explosive. Hence, an explosive with a

small critical diameter is more sensitive than one with a much larger critical diameter. Conversely, unconfined AN/FO explosives exhibit an increased sensitivity with an increased charge diameter. When the same explosive is confined in steel pipe, sensitivity was observed to decrease with increasing charge diameter.

Detonation velocity generally increases with increased confinement and with increased charge diameter.

2.2.2.4 Particle Geometry

Particle size and shape of the ammonium nitrate influence both the sensitivity and the brisance of ammonium nitrate explosives. Thus, porous prills present a larger surface area than do dense ones and, other things being equal, are more sensitive to blasting cap detonation than are dense prills. Fine particle size ammonium nitrate admixed with various combustibles is more sensitive than coarse ammonium nitrate. Explosive charges composed of small particles have higher detonation velocities than do charges composed of large particles. This is in agreement with the theory that explosive grains react by surface burning rather than by adiabatic, homogeneous, thermal decomposition for ammonium nitrate explosives which have relatively long reaction zones. The detonation velocity (2000-3000 meters per second) is very sensitive to geometric parameters near the failure diameter of the charge.

2.2.2.5 Bulk Density

As a rule, the blasting cap sensitivity of ammonium nitrate explosives decreases rapidly with an increase in bulk density. AN/FO explosive mixtures, which are of particular interest to this program, are reported to exhibit a sharp decrease in sensitivity at densities much greater than 0.9 gm/cc. This abrupt transition with increasing density is probably caused by loss of intimate contact between ammonium nitrate and the fuel oil and by a decrease in total

surface area. Sensitizers which yield solid solutions with ammonium nitrate should not exhibit this behavior.

Detonation velocity of AN/FO explosives increases sharply with an increase in charge density up to the limiting density of approximately 1 gm/cc. Above the limiting value detonation velocity is relatively insensitive to variations in density.

III. Results

3.1 A Comparison of Products

Fuel oil/FGAN explosives were prepared from Stengel, prilled and crystallization processed ammonium nitrate and were tested for sensitivity and brisance to observe similarities or differences between ammonium nitrates prepared by these three processes. Representative samples of each (Table I) were pulverized with a type C-F micropulverizer and screened to obtain three fractions as follows; (1) through 60 on 170 mesh, (2) through 170 on 200 mesh and (3) through 200 mesh. Each of the nine samples was blended with 6 weight per cent of Number 2 fuel oil by tumbling the samples through a screened mixing barrel for one hour at approximately 35° C. The explosive mixtures were then placed in an 8-inch long by 2-inch inside diameter length of continuously-welded, schedule 40 carbon steel pipe. This pipe had been previously welded to the center of an 8-inch-square by 0.25-inch-thick sheet of M1020 merchant quality steel witness plate. The initiator was imbedded as illustrated in Figure 1. The test fixture was placed on a second witness plate which was supported on a pair of 2-inch steel blocks located under opposite edges of the witness plate.

Each of the nine mixtures responded to a Number 6 blasting cap as evidenced by damage to the witness plates. The results are presented in Table II.

A positive test, viz., a detonation, was characterized by a torn, punctured or shattered witness plate. A dented plate was interpreted as an incomplete detonation. In general, brisance could be related to the extent of fragmentation of the test fixture. The most brisant mixtures produced a high degree of fragmentation of both the pipe and the witness plate.

Table I. FGAN Compositions Tested

Manufacturing Processes	Manufacturer	Commercial Designation	Coating	Reported Bulk Density
Prilling	Monsanto Chemical Co.	Dense E-2	Unknown	60 lb/ft ³
Stengel	Commercial Solvents Corp.	Hi-D	Unknown Inorganic, 2 to 3%	58.4 lb/ft ³
Crystalline	E. I. DuPont	Technical Grade	None	Unknown

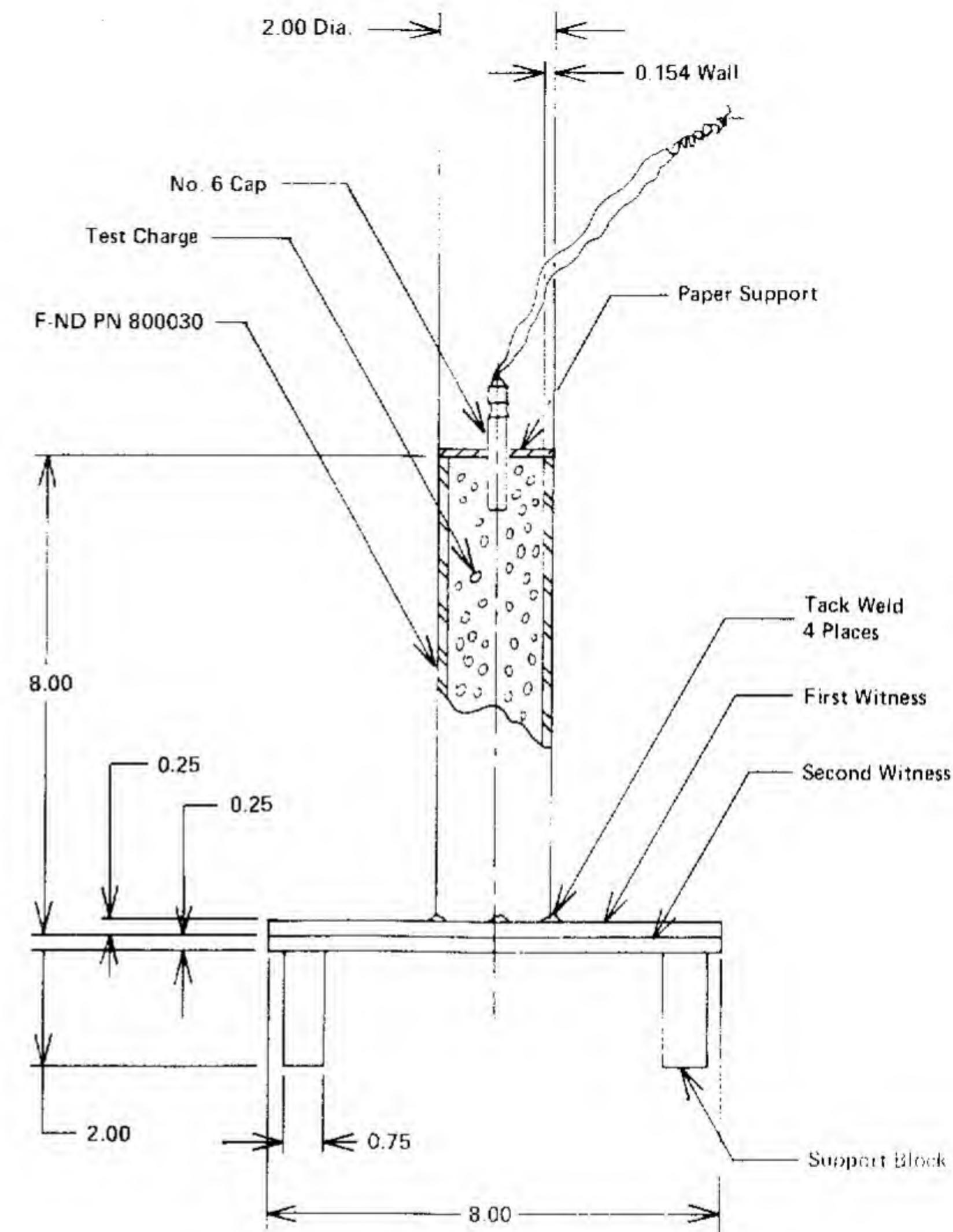


Figure 1. Explosive Test Fixture

Table II. Ammonium Nitrate/6 Per Cent Fuel Oil Mixtures: A Comparison of Prilled, Stengel and Crystallization Processed Material.

INITIATOR	PRILLS			STENGEL			CRYSTAL		
	Mesh -60, +170	Mesh -170, +200	Mesh -200	Mesh -60, +170	Mesh -170, +200	Mesh -200	Mesh -60, +170	Mesh -170, +200	Mesh -200
1 No. 6 EBC ^a	Puncture ^c	Puncture	Dent	Puncture	Dent	Dent	Puncture	Puncture	Puncture
1 No. 8 EBC and No. 6 BC ^b	Puncture	Puncture	Tear	Dent	Dent	Dent	Puncture	Puncture	Puncture
1 No. 8 EBC and 5 gm Tetryl	Puncture	Puncture	Puncture	Dent	Dent	Dent	Puncture	Tear	Puncture
1 No. 8 EBC and 10 gm Tetryl	Puncture	Puncture	Dent	Puncture	Tear	Dent	Puncture	Dent	Puncture
1 No. 8 EBC and 100 gm C-4	Puncture	Puncture	Dent	Dent	Dent	Dent	Puncture	Puncture	Puncture

^aElectric blasting cap.

^bNonelectric blasting cap.

^cDescribes damage to witness plate.

Note: Packing density is an unknown on these tests.

The crystallization process ammonium nitrate and the dense prill explosives appear to be more reactive than the Stengel process explosives. It is difficult to rationalize the observation since the principal difference between the three types of FGAN is particle configuration, which was neutralized by pulverizing the materials prior to testing.

Since prilled FGAN is the most common form available and it functioned satisfactorily in the preliminary testing, it was used throughout the remainder of the program. The product of several manufacturers was used without any significant difference in performance.

3.2 Evaluation of Indigenous Sensitizers

Tables III and IV summarize the results of the preliminary evaluation of 23 potential indigenous sensitizers for FGAN. The prills were micropulverized as described above and were subsequently screened to yield three fractions, sizes -60 to +170 mesh, -170 to +200 mesh and -200 mesh. Each fraction was mixed with 3, 6 and 9 per cent of each indigenous sensitizer by blending in an inclined tumbler for 15 minutes with occasional stirring by a hand-held wooden paddle. The tumbler resembled a small cement mixer.

Approximately 300 grams of each composition were poured into the standard test fixtures without tamping (Figure 1). The compositions were tested with a Number 6 electric blasting cap. The hydrocarbon additives sensitized pulverized FGAN to detonation with a single Number 6 cap in the 6 to 9 weight per cent concentration range. Aluminum and magnesium powder sensitized pulverized FGAN to detonation with a Number 6 cap at 9 weight per cent concentration. It is difficult to rationalize the fact that the coarser FGAN yields more sensitive mixtures since in later testing, sensitivity was observed to increase with decreasing particle size.

A number of candidate sensitizers which did not respond to initiation by a single Number 6 blasting cap were tested at higher initiation levels in an effort to either establish an acceptable threshold sensitivity limit or to discard the

Table III. Effect of Various Additives on FGAN Using a Single Number 6 Blasting Cap

Sensitizer	Weight Per Cent	Damage to Witness Plate at Various FGAN Particle Sizes		
		-60 + 150 Mesh	-150 + 200 Mesh	-200 Mesh
Union No. 2 Fuel Oil	3	Torn	Dented	Torn
	6	Punctured	Torn	Torn
	9	Punctured	Punctured	Dented
SAE 30 Motor Oil	3	No Response	No Response	No Response
	6	Torn	Dented	Dented
	9	Torn	Dented	Dented
1:1 Regular Gasoline/ Motor Oil	3	Torn	Dented	Dented
	6	Torn	Punctured	Torn
	9	Punctured	Punctured	Dented
Automatic Transmission Fluid	3	Torn	Torn	Dented
	6	No Response	Torn	No Response
	9	No Response	Punctured	Dented
Ethylene Glycol	3	Torn	Dented	No Response
	6	Torn	Torn	Torn
	9	Torn	Punctured	Punctured
Aluminum Powder 22 μ	3	No Response	No Response	Dented
	6	Dented	No Response	Torn
	9	Torn	Dented	Torn
Magnesium Powder 22 μ	3	No Response	No Response	No Response
	6	Torn	No Response	No Response
	9	Dented	Torn	Dented
Pine Sawdust	3	No Response	No Response	No Response
	6	No Response	No Response	No Response
	9	Dented	No Response	No Response
Zinc Chromate	3	No Response	No Response	No Response
	6	No Response	No Response	No Response
	9	No Response	No Response	Punctured
Paint Thinner	5	Punctured	Dented	Torn

Table IV. Nonsensitizers for FGAN at 3, 6 and 9 Weight Per Cent Levels and One Number 6 Electric Blasting Cap

Ammonium Dichromate
Barium Chromate
Lead Chromate
Smokeless Powder
Lamp Black
Pulverized Charcoal
Burnt Sugar
Sugar
Coconut Oil
Coal Dust
Pipe Tobacco
Ammonium Chloride
p-Dichlorobenzene

material as an ineffective sensitizer. Testing was performed in the standard test fixture. With the exception of granulated sugar, all of the materials sensitized FGAN to initiation with four Number 6 blasting caps. The results are summarized in Table V. The data suggest that fuel oil is perhaps the most reliable sensitizer of the lot.

3.3 Improvised Comminution Techniques

Several improvised techniques were examined for comminuting FGAN prills.

The least tiring comminuting method, which also produced the finest particle size, consisted of crushing a handful of prills at a time by rubbing between two wooden boards for about 15 minutes to produce a powder resembling flour.

Similar results could be obtained by grinding the prills between two flat rocks or bricks. This method was characterized by minor inconveniences which included repeated spillage of incompletely ground prills and abrasion of the brick surfaces. This resulted in brick dust contamination of the ammonium nitrate.

Ammonium nitrate prills were also effectively crushed beneath a rolling pin on a hard wooden surface. A rolling and grinding motion, achieved by slanting the rolling pin at about a 45-degree angle to the direction of motion and the board, yielded a product with a particle size which resembled granulated sugar. This is a more tedious operation than either the brick method or the two-board method.

Comminution could be achieved underfoot by stomping, rolling and pivoting a foot shod with a hard-soled shoe over the prills on a hard (wooden or masonry) surface. This produced extreme wear on the shoes and required more effort than any of the above procedures. By far, the most tedious, least useful procedure consisted of pounding ammonium nitrate prills with the edge of a heavy board. This method was only casually examined.

Comminuted material prepared by the rolling pin, brick, board-on-board and underfoot methods was subjected to screen size analysis. The particle size distribution obtained by each of the four methods is presented in Table VI.

Table V. Threshold Sensitivity Limits for Some Marginal FGAN Sensitizers

Sensitizer	Weight Per Cent	Number of No. 6 Blasting Caps	-60 + 150 Mesh Ammonium Nitrate	Number of No. 6 Blasting Caps	-150 + 200 Mesh Ammonium Nitrate	Number of No. 6 Blasting Caps	-200 Mesh Ammonium Nitrate	Damage to Witness Plate
Union No. 2 Fuel Oil	5	1	Punctured	1	Punctured	1	Punctured	Punctured
SAE 30 Motor Oil	5	1	Torn	1	Dented	1	Dented	Dented
Regular Gasoline/Motor Oil	2.5/2.5	1	Torn	1	Punctured	1	Torn	Torn
Ethylene Glycol	5	1	Torn	1	Torn	1	Torn	Torn
Fuel Oil/NH ₄ C1	4/1	1	Punctured	1	Punctured	1	Punctured	Punctured
Fuel Oil/p-dichlorobenzene	4/1	1	Punctured	1	Punctured	1	Dented	Dented
Paraffin Wax	5	4	Punctured	4	Punctured	4	Dented	Dented
Paint Thinner	5	1	Punctured	1	Dented	1	Torn	Torn

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Automatic Transmission Fluid	5	1	Dented	1	Punctured	1	Punctured
Aluminum Powder (22μ)	10	1	Torn	1	Dented	1	Torn
Magnesium Powder (22μ)	10	1	Dented	1	Torn	1	Dented
Pine Sawdust	10	4	Torn	4	Dented	4	Dented
Powdered Coal dust	10	2	Torn	4	No Response	4	No Response
Powdered Charcoal	10	4	No Response	4	Punctured	4	Torn
Flour	10	1	Torn	2	Dented	2	Dented
Flour	10	4	Punctured	4	Punctured	4	Punctured
Dried, Ground Mule Dung	10	4	Torn	4	Dented	4	Dented
Granulated Sugar	10	4	No Response	4	No Response	4	No Response
Melted Sugar	10	2	Punctured	2	Torn	2,4	Torn
Lamp Black	10	4	No Response	4	No Response	4	Torn
Pipe Tobacco	10	2	Dented	2	Torn	4	Dented

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Table VI. Particle Size Distribution Obtained By Improvised Commminution of FGAN.

Screen Mesh	Per Cent FGAN Particles			
	Rolling Pin Method	Board Method	Brick Method	Shoe Method
On 24	16	18	18	24
Through 24 on 48	23	5	24	20
Through 48 on 100	34	8	23	28
Through 100 on 200	17	15	30	23
Through 200	10	34	5	5

3.4 Effect of Improvised Commminution Methods on Sensitivity

To determine the effect of the particle size distribution obtained by the various improvised commminution methods on the sensitivity of explosives which had been previously prepared with micropulverized and screened FGAN, a series of sensitivity measurements was made using blasting caps. The same technique and the standard test fixture used in the experiments described in Sections 3.1 and 3.2 were employed. All liquid fuel mixtures were prepared 24 hours before testing to ensure that the FGAN particles were thoroughly wetted. Mixtures were compacted to a minimum density of 0.75 gm/cc in the test fixture prior to initiation.

The results demonstrated that the brick comminuted and the wood-on-wood comminuted FGAN yielded more sensitive mixes than did either the shoe or the rolling pin crushed material. This is in agreement with the observation that fine particle size ammonium nitrate admixed with combustibles is more sensitive and more brisant than coarse ammonium nitrate (see Section 2.2.2.4).

3.5 Variables Affecting Sensitivity

Packing density, particle size, confinement and charge diameter were investigated to determine the conditions necessary to initiate sensitized FGAN with a single Number 8 electric blasting cap.

Prilled FGAN thoroughly mixed with 5-weight per cent fuel oil could not be initiated to detonation in a 2-inch steel pipe with four Number 6 blasting caps. Likewise, prills which were allowed to soak in fuel oil from 1 to 24 hours and then drained dry could not be detonated either as prills or as finely ground material in a 2-inch steel pipe with a single Number 8 blasting cap. Results are summarized in Table VII.

A series of tests was conducted using 5-weight per cent fuel oil sensitized FGAN to determine the maximum packing density in a 2-inch steel pipe which could be initiated to detonation using a single Number 8 blasting cap. The FGAN

Table VIII. FGAN Prills^a/Fuel Oil Sensitized Experiments

<u>Fuel Oil/FGAN</u>	<u>Mix Packing Density (gm/cc)</u>	<u>Initiator</u>	<u>Remarks</u>
Prills immersed 1 hour in fuel oil, drained dry	1.04	1 No. 8 Cap	Slight dent in witness plate, pipe slightly bulged
Prills immersed 24 hours in fuel oil, drained dry, then ground between wood boards	1.2	1 No. 8 Cap	Slight dent in witness plate, pipe slightly bulged
Prills mixed with five weight per cent fuel oil	0.85	4 No. 6 Caps	Slight dent in witness plate, pipe slightly bulged

^aPrill density = 0.88 gm/cc

was previously ground to the consistency of flour between two boards. Detonation, as evidenced by a punctured witness plate, was repeatedly obtained at packing densities below 0.78 gm/cc. Explosions were repeatedly and reproducibly induced with a single Number 8 blasting cap at packing densities less than 0.88 gm/cc. The explosions were characterized by a shattered pipe and a severely dented, but unpunctured witness plate. The results are presented in Table VIII.

An explosion or a detonation of fuel oil sensitized, finely ground FGAN could also be initiated with one Number 8 blasting cap in a 1-inch diameter by 4-inch length of steel pipe, in an old evaporated milk can, a small wide mouth glass container, in a beer bottle from which the narrow neck had previously been removed, and in 2-inch diameter by 8-inch long cardboard tubes (Table IX).

3.6 Miscellaneous Sensitizers

Equal parts of motor oil and gasoline may be used in place of fuel oil as a sensitizer, and FGAN containing approximately 2 per cent of soap chips or Tide detergent, in addition to 5 per cent fuel oil, could be detonated at higher packing densities with one Number 8 blasting cap than could the soap-free mixture. Aluminum powder or flake at 25 weight per cent concentration was a satisfactory sensitizer although wheat flour was ineffective. These results are presented in Table X.

3.7 Alternate Initiation Methods

A series of experiments was performed to establish conditions for detonation of FGAN explosives by alternate initiators in the event that blasting caps would be unavailable.

3.7.1 Smokeless Powder - Safety Fuse Initiators

Eight-inch lengths of 2-inch diameter standard steel pipe, threaded at both ends, were used as test vessels. Mix-

Table VIII. Comminuted FGAN Containing Five Weight Per Cent Fuel Oil

Packing Density (gm/cc)	Initiator	Remarks
0.95	5 No. 6 Caps	Detonation
0.95	4 No. 6 Caps	Deep dent in witness plate, pipe was shattered
0.94	1 No. 8 Cap	No Reaction
0.88	1 No. 8 Cap	Deep dent in witness plate, pipe was shattered
0.87	1 No. 8 Cap	Deep dent in witness plate, pipe was shattered
0.86	1 No. 8 Cap	Deep dent in witness plate, pipe was shattered
0.85	1 No. 8 Cap	Deep dent in witness plate, pipe was shattered
0.84	1 No. 8 Cap	Deep dent in witness plate, pipe was shattered
0.84	1 No. 8 Cap	Detonation
0.83	1 No. 8 Cap	Deep dent
0.78	1 No. 8 Cap	Deep dent
0.77	1 No. 8 Cap	Detonation
0.76	1 No. 6 Cap	Detonation
0.68	1 No. 8 Cap	Detonation
0.66	1 No. 8 Cap	Detonation
0.65	1 No. 8 Cap	Detonation
0.61	1 No. 6 Cap	Detonation
0.61	1 No. 8 Cap	Detonation
0.59	1 No. 8 Cap	Detonation
0.58	1 No. 8 Cap	Detonation
0.56	1 No. 8 Cap	Detonation

NOTES:

1. FGAN prills comminuted between 2 wooden boards to consistency of flour; nominal density of ground material is 1.02.
2. Fuel-to-powdered FGAN volume ratio is about 1:16.
3. Tests were conducted in 2-inch I.D. by 8-inch long steel pipe, spot-welded to 1/4 inch steel plate.

Table IX. Comminuted FGAN Containing Five Weight Per Cent Fuel Oil in Miscellaneous Containers on 0.25-Inch Witness Plate

Packing Density (gm/cc)	Confinement	Initiator	Remarks
0.526	1-1/2" I.D. x 6" steel pipe	1 No. 8 Cap	Detonated
0.607	1" I.D. x 4" steel pipe	1 No. 8 Cap	Deep dent in witness plate, can shattered
	Evaporated Milk Can	1 No. 8 Cap	
	Beer bottle (neck removed)	1 No. 8 Cap	Witness plate torn
	Loose Fill	1 No. 8 Cap	Detonated
	Loose Fill	1 No. 8 Cap	Detonated
	Loose Fill	2 No. 8 Caps	Detonated
0.70	2-1/2" x 6-1/2" glass bottle	1 No. 8 Cap	
0.57	2" x 8" cardboard	2" x 8" cardboard	

tures of FGAN containing the indigenous sensitizer were placed in the pipe which previously had been capped at one end. A bagged 5-gram or 100-gram charge of TMR 4350 powder was placed on top of the FGAN mixture, and the pipe was closed with a cap containing a central hole through which a short length of fuse was inserted. The sensitizers tested were 6 per cent fuel oil and either 1 per cent barium chromate or 1 per cent lead chromate. The particle size of the FGAN was varied from to 60 to 200 mesh.

Although the end caps were generally ruptured upon ignition of the smokeless powder, none of the pipes fragmented. A control experiment in which a Number 6 blasting cap replaced the smokeless powder resulted in complete fragmentation of the weapon.

3.7.2 Initiation by Heat

To determine the sensitivity to initiation by heating, FGAN sensitized mixtures were placed in 8-inch lengths of 2-inch diameter standard steel pipe which were sealed at both ends with threaded caps, and were heated over burning rags and fuel oil. None of the mixtures exploded under these conditions. In these experiments either the pipe caps ruptured, the bomb leaked around the threads or the pipe split open with very little explosive force. The experiments therefore were repeated in steel pipe which was rated for 3,000 psi service. The pipe threads were coated with sealant before capping. Of the seven formulations tested, only the zinc chromate paint/ammonium nitrate mixture and the fuel oil/ammonium chloride/ammonium nitrate mixtures detonated. The remaining mixtures, all of which were sensitive to blasting caps, failed to explode. These results are summarized in Table XI.

3.7.3 Brisance Evaluation

Selected FGAN explosive compositions were evaluated for brisance using the standard lead block (Trauzl) test. There was no appreciable difference between the various mixtures

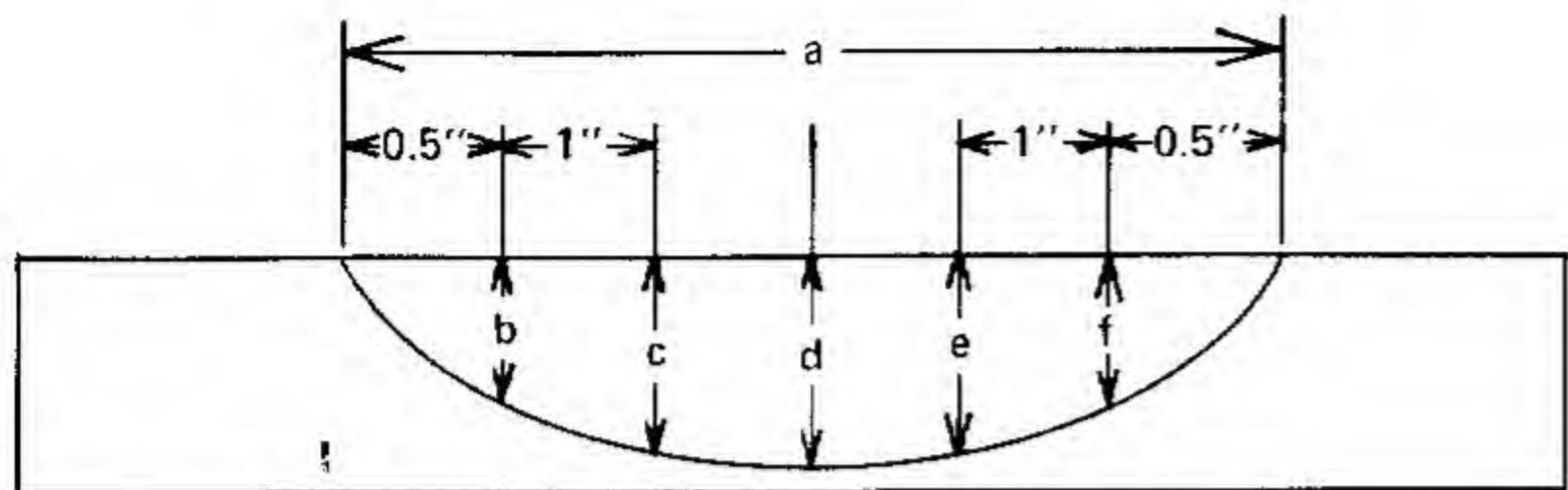
Table X. FGAN - Miscellaneous Sensitizers

Packing Density (gm/cc)	Sensitizer	Weight Per Cent	Volume Ratio Sensitizer/FGAN	Initiator	Remarks
0.91	30 wt motor oil	5	1/16	5 No. 6 caps	Detonated
0.91	30 wt motor oil	5	1/16	4 No. 6 caps	Deep dent in witness plate, pipe shattered
0.97	Motor oil/regular gas	2.5/2.5	1/1:32	4 No. 6 caps	Detonated
0.97	Motor oil/regular gas	2.5/2.5	1/1:32	2 No. 6 caps	Deep dent in witness plate, pipe shattered
0.66	Motor oil/regular gas	2.5/2.5	1/1:32	1 No. 6 cap	Detonated
0.57	Motor oil/regular gas	2.5/2.5	1/1:32	1 No. 8 cap	2" x 8" cardboard confinement, deep dent in witness plate
0.96	Soap chips/fuel oil	2/5	1.1/18	1 No. 8 cap	Detonated
0.87	Soap chips/fuel oil	2/5	1.1/18	1 No. 8 cap	Detonated
0.84	"Tide" /fuel oil	2/5	1.1/16	1 No. 8 cap	Detonated
0.95	A1 powder	25	1/4 (prills)	1 No. 8 cap	Deep dent in witness plate, pipe shattered
0.90	A1 powder	25	1/4 (prills)	2 No. 8 caps	Deep dent in witness plate, pipe bulged
0.95	A1 powder	25	1/3	1 No. 8 cap	Deep dent in witness plate, pipe fragmented
0.80	A1 flakes	25	1/1	1 No. 8 cap	Deep dent in witness plate, pipe shattered
0.70	A1 flakes	25	1/1	1 No. 8 cap	Detonated
0.71	A1 flakes	25	1/1	1 No. 8 cap	2" x 8" cardboard confinement, deep dent in witness plate
1.01	Flour	5	1/16	4 No. 6 caps	Slight dent in witness plate
0.84	Flour	25	2/5	2 No. 8 caps	Slight dent in witness plate, pipe bulged
0.79	Flour	25	2/5	2 No. 8 caps	2" x 8" cardboard, no reaction

under the conditions selected for testing. The testing consisted of detonating 300-gram samples in a 2-inch diameter shot pipe which stood erect on a 2-inch-thick by 5-inch-square lead block. An equivalent quantity of riced TNT was used as a reference. The results are presented in Table XII.

<u>Explosive Mixture</u>	<u>Results</u>
Fuel Oil Number 2	No detonation
Paint Thinner	No detonation
Ethylene Glycol	No detonation
Zn Chromate Paint/Ammonium Chloride (150 mesh AN) 4%/1%	No detonation - pipe split longitudinally 8 minutes after ignition
Aluminum Powder	No detonation
Zinc Chromate Paint 10% (150 mesh AN)	Detonation 11 minutes after igniting fuel oil
Fuel Oil/Ammonium Chloride 4%/1%	Detonation 15 minutes after igniting fuel oil

Table XII. Brisance Tests



Lead Block Configuration

Explosive Mixture	Dimension (inch)					
	a	b	c	d	e	f
Riced TNT	4.5	1.1	1.3	1.4	1.3	1.0
C-4 Explosive						
FGAN (brick pulverized) plus 4% fuel oil plus 1% ammonium chloride	4.0	0.7	1.0	1.1	1.0	0.7
FGAN (brick pulverized) plus 5% ethylene glycol	3.8	0.7	0.9	1.0	0.9	0.7
FGAN (brick pulverized) plus 10% aluminum powder	4.6	0.9	1.3	1.4	1.3	0.9
FGAN (brick pulverized) plus 5% fuel oil No. 2	4.2	0.8	1.1	1.1	1.1	0.8
FGAN (brick pulverized) plus 5% paint thinner	4.0	0.7	1.0	1.0	1.0	0.7
FGAN (shoe pulverized) plus 5% paint thinner	4.0	0.7	1.0	1.1	1.0	0.7
FGAN (rolling pin pulverized) plus 5% paint thinner	4.2	0.7	1.1	1.2	1.1	0.6

IV. Conclusions

Commercial fertilizer grade ammonium nitrate (FGAN), either as received or finely pulverized, is insensitive to at least five Number 6 electric blasting caps when confined in a 2-inch diameter steel pipe.

Mixtures of as-received (prilled) FGAN containing 25 weight per cent powdered or flaked aluminum, confined in either 2-inch diameter steel or cardboard may be initiated to explosive decomposition with a single Number 8 electric blasting cap.

Prilled FGAN mixed with 5 weight per cent fuel oil or with 10 weight per cent sawdust or mule dung is insensitive to one Number 6 electric blasting cap in 2-inch diameter steel confinement.

Finely pulverized FGAN intimately mixed with 5 weight per cent fuel oil, motor oil, motor oil/gasoline mixtures, ethylene glycol, and paint thinner may be detonated with a single Number 8 electric blasting cap when confined in 1- or 2-inch diameter steel, 2-inch diameter cardboard, nominal 2.5-inch diameter "tin" cans and beer bottles, provided that the packing density is less than 0.78gm/cc. Packing densities less than 0.78 gm/cc can be assured by filling the containers without tamping.

Pulverized FGAN is sensitized to some degree when intimately mixed with 10 weight per cent pine sawdust, powdered coal, powdered charcoal, dried mule dung, or pipe tobacco. These mixtures frequently, but not always, may be initiated to explosive decomposition in 2-inch steel confinement, but require more than four Number 6 or three Number 8 electric blasting caps.

Small amounts of either powdered household detergent or soap chips appear to increase the sensitivity of FGAN/FO mixtures, detonations were observed at packing densities of 0.96 gm/cc. This effect has not been thoroughly investigated.

The sensitized FGAN mixtures that were confined in sealed steel pipe could not be initiated reliably when heated in an open fire.

The sensitized FGAN mixtures which can be initiated with one Number 8 blasting cap are nearly as brisant as riced trinitrotoluene (TNT).

Detailed instructions for the preparation of sensitized FGAN-containing munitions are presented in the Appendix.

APPENDIX

INSTRUCTIONS FOR THE PREPARATION OF FERTILIZER EXPLOSIVE

Fertilizer Explosive

An explosive munition can be made from fertilizer grade ammonium nitrate and either fuel oil or a mixture of equal parts of motor oil and gasoline. When properly prepared, this explosive munition can be detonated with a Number 8 blasting cap.

MATERIAL REQUIRED

Ammonium nitrate (not less than 32% nitrogen)

Fuel oil
or
Gasoline and motor oil

Two flat boards, bricks, etc.
(for comfort and efficiency
one of these should be com-
fortably held in the hand, the
other should be about 30 in-
ches square or larger)

Bucket or other container
for mixing ingredients

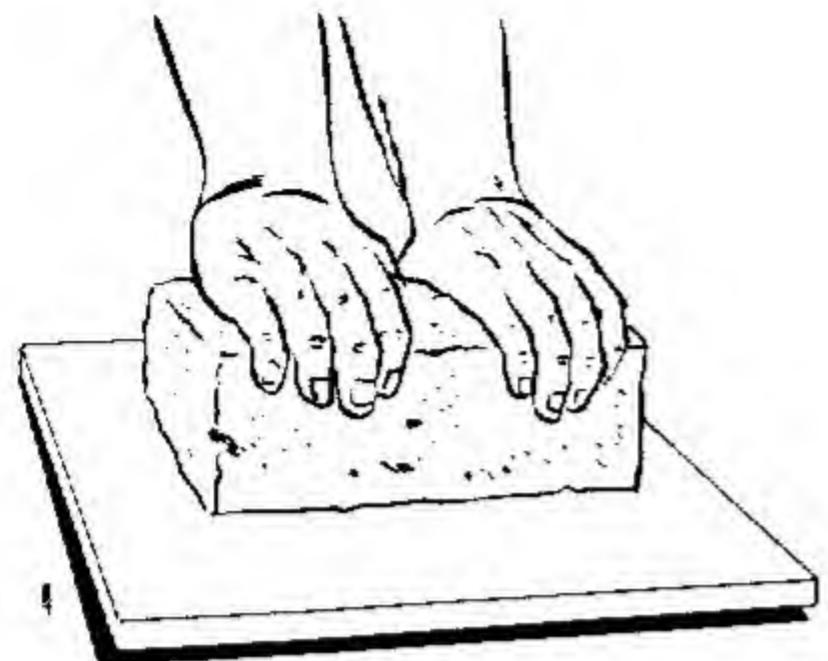
Iron or steel pipe
or
Bottle, tin can or heavy-walled
cardboard tube

Number 8 blasting cap

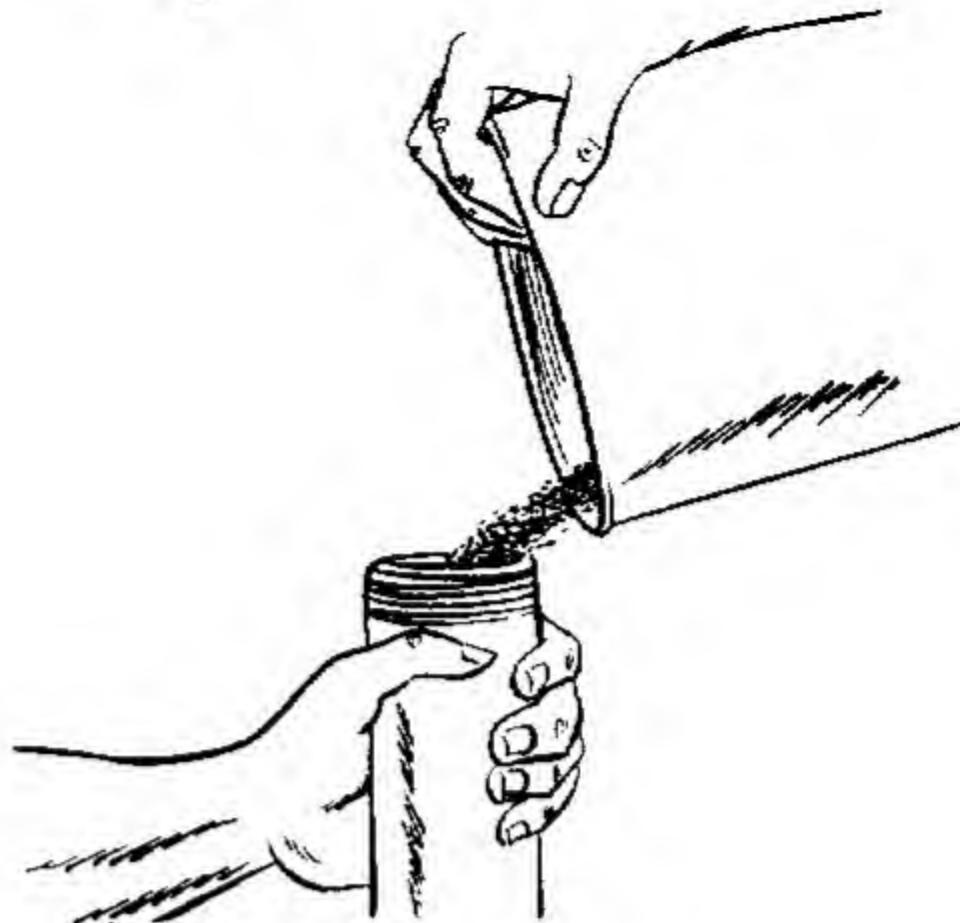
HOW USED

Fertilizer
Explosives manufacture
Medicine

Diesel fuel
Heating oil



1. Spread a handful of the ammonium nitrate on a flat, hard surface and rub vigorously until the large particles are crushed into a very fine powder that looks like flour. Proceed with Step 2 as soon as possible since the powder may take moisture from the air and become spoiled.



3. Pour this mixture loosely into an iron or steel pipe which has been capped at one end. Take care not to tamp or shake the mixture in the pipe. If it becomes tightly packed, one cap will not be sufficient to initiate the explosive. If a pipe is not available, you may use a dry tin can, a glass jar or a heavy-walled cardboard tube.



2. Mix one measure of fuel oil with 16 measures of the finely ground ammonium nitrate by stirring together in a dry bucket or other suitable container. If fuel oil is not available, use one-half measure of gasoline and one-half measure of motor oil. Store in a waterproof container until ready to use.



4. Insert blasting cap just beneath the surface of the explosive mix.